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Electron Excitation and Ionization Rate Coefficients For N_2, O_2, NO, N and O

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1. INTRODUCTION

The ionization of air species by charged particle beams and radiation sources, such as microwaves, lasers, uv, x-ray and γ-rays, generates secondary electrons. These secondary electrons lose their energy through inelastic and elastic collisions with the air species. However, to obtain the rate of energy loss by these electrons in air one must know the rate of energy loss for each inelastic process. The inelastic processes are numerous and include ionization, dissociation, electronic states excitations, vibrational and rotational states excitations of the molecular species.

To obtain the rates for various electron-air species collisions one must know the appropriate electron velocity distribution and the relevant collision cross sections. If the electron velocity distribution is Maxwellian, then the excitation rate coefficient can be expressed as [1]

$$X_{ij} = \langle \sigma_{ij} \quad V \rangle = K_o \, T^{-3/2} \int E \, \sigma_{ij}(E) \, e^{-E/T} dE, \tag{1}$$

where $K_o = 6.697 \times 10^7$. Here X_{ij} indicates the excitation from state i to j whose cross section is $\sigma_{ij}(E)$ where E is the electron energy, and T is the electron temperature in units of eV. Generally, one obtains a fit[1] for each portion of σ by one or more terms of the polynomial $C_o + C_1E + C_2E^2 + C_3E^3$, or by an exponential term such as $C_e \, e^{-\alpha E}$, or by a combination of the two. Each section of the cross section can then be used in Equation (1) and integrated analytically. For typical integrals which may arise, see Eq. (3) of Ref. (1). Then the total rate coefficient for any excitation is obtained by summing over the rate coefficients obtained for each section.

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In this report we follow this procedure and present relevant excitation and ionization rate coefficients for air species, N_2, O_2, N, O and NO. This report is a revision of a previous report by Ali and Anderson.[2] Since then, however, better theoretical and experimental cross section data have become available. A set of cross sections utilized to obtain the appropriate rates is reported elsewhere.[3]

2. N_2

2.1 Vibrational Excitation Rate Coefficients

The electron impact excitation rate coefficients for eight ground state vibrational levels of N_2 are given in Table 1 as a function of electron temperature. These rates reflect the normalization of the total cross section[4] to $\sim 6 \times 10^{-16}$ cm^2 at an electron energy of 2.5 eV.

2.2 N_2 Triplet States Excitation Rate Coefficients

The excitation rate coefficients for the triplet states $A^3\Sigma$, $B^3\pi$, $C^3\pi$, $B'^3\Sigma$ and $W^3\Delta$ are presented in Table II. They are obtained, except for the $A^3\Sigma$ state, using the measured cross sections of Cartwright, et al.[5] These rate coefficients are in good agreement with the calculations of Cartwright[6]. For the $A^3\Sigma$, however, we have utilized the measured cross section of Borst[7] because of its $\bar{E}^3$ fall off feature at higher energies and lowered the values in the peak region to coincide with the peak value obtained by Cartwright, et al[5].

2.3 N_2 Singlet States Excitation Rate Coefficients

The rate coefficients for the excitations of the following singlet states, $a'^1\Sigma_u$, $a^1\pi_g$, $w^1\Delta_u$ and $a''^1\Sigma_g$ are presented in Table III. These rates are obtained using the measured cross sections of Cartwright, et al.[5] Other higher energy singlets and triplets are included in the dissociation rate as discussed in the next section.

2.4 N_2 Dissociation Rate Coefficient

The rate coefficient for the dissociation of N_2, given in Table IV, is obtained from the measurements of Zipf and McLaughlin[8] which is in good agreement with previous measurements (see Ref. 3 for details). This cross section, however, contains, through predissociation, the cross sections for a large number of higher lying singlet states, e.g. $b^1\pi$,

$c^1\pi$, $b^1\Sigma_u$, $o^1\pi_u$, $d^1\Sigma_u$ and ~20% contribution from a $^1\pi_g$ state. For this reason, individual excitation rate coefficients for these and other contributing states are not provided in this report.

2.5 N_2 Ionization and Dissociative Ionization Rate Coefficients

The dissociative ionization rate coefficient for N_2 is obtained by using the measured cross section of Rapp, et al[9]. On the other hand, the ionization rate coefficient is obtained by using the cross section of Rapp and Golden[10]. These rate coefficients are given in Table IV.

3. O_2

3.1 O_2 Ionization, Dissociative Ionization and Dissociative Attachment Rate Coefficients

The dissociative ionization rate coefficient for O_2 is obtained using the cross section measured by Rapp and Golden[10]. While the ionization rate coefficient is obtained using the cross section measured by Rapp, et al[9]. These rate coefficients are given in Table V, along with the dissociative attachment rate coefficient. The cross section for the dissociative attachment is from Rapp and Briglia[11].

3.2 O_2 Dissociation Rate Coefficient

The excitation rate coefficients for the $B^3\Sigma$ state and the sum of $A^3\Sigma$, $C^3\Delta$ and $C^1\Sigma$ are presented in Table VI. These excitations generally lead to the dissociation of the molecule and thus their rates can be considered as the dissociation rate for O_2. The $B^3\Sigma$ state cross section is based on the measurement of Wakiya[12] and the theoretical calculation of Lin and Chung[13], and Green and Stolarski[14].

The excitation rate coefficient for the sum of the $A^3\Sigma$, $C^3\Delta$ and $C^1\Sigma$ states was obtained using the measured cross section of Wakiya[15] and the theoretical expression of Green and Stolarski[14]. It should be noted that the dissociation of the $A^3\Sigma$ state leads to two oxygen atoms in the ground state while the dissociation of the $B^3\Sigma$ state leads to one atom in the ground state and the other in the excited state, (O^1D).

3.3 Excitation Rate Coefficients for the low lying electronic states of O_2

The excitation rate coefficients for two low lying metastable electronic states of O_2, i.e., $a^1\Delta$ and $b^1\Sigma$ are given in Table VI. The

coefficients are based on cross sections of Linder and Schmidt[16], Trajmar, et al[17], and Wakiya[15].

3.4 Vibrational Excitation Rate Coefficients

The excitation rate coefficients for three ground state vibrational levels of O_2 are given in Table VII. The cross sections are obtained from the measurements of Linder and Schmidt.[16]

4. N

4.1 Low Lying Metastable States of N

The excitation rate coefficients for the low lying metastable states of N, i.e., ^2D and ^2P are given in Table VIII along with the coefficient for the excitation of the ^2D to ^2P transition. These rate coefficients are obtained using the calculated cross sections of Berrington et al[18] and agree reasonably well with the rates obtained previously by Ali[19] where the same cross sections were used.

4.2 Ionization Rate Coefficient of N

The ionization rate coefficient for nitrogen atom is presented in Table VIII and is taken from Reference 2.

5. O

5.1 Low lying Metastable States of O

The excitation rate coefficients for the low lying metastable states of O, i.e., ^1D and ^1S are given in Table IX, along with the rate coefficient for the ^1D - ^1S transition. These rate coefficients are obtained by using the calculated cross sections of Thomas and Nisbet[20] and agree reasonably well with the rates obtained previously by Ali[19], where the same cross sections were utilized.

5.2 Ionization Rate Coefficient of O

The ionization rate coefficient for the atomic oxygen is presented in Table IX and is taken from Reference 2.

6. NO

The ionization rate coefficient of NO is presented in Table X and is based on the measured cross section of Rapp and Golden[10].

7. Momentum Transfer Rate Coefficient

The rate coefficients for the electron momentum transfer is N_2, O_2 and O are presented in Table XI. The corresponding cross sections are from References 21, 22 and 23, respectively.

8. Expressions for the Rate Coefficients

Most of the rate coefficients presented in Tables II through XI were fitted to the following expression

$$R = (b_o + b_1 T + b_2 T^2)\ T^{-\frac{1}{2}}\ \mathrm{Exp}\left(-\frac{E_{th}}{T}\right), \qquad (2)$$

where E_{th} is the threshold energy for the process of interest. The coefficients b_o, b_1 and b_2 are presented in Table XII over two temperature intervals of T=o $\rightarrow$ 5 eV and T = 5 $\rightarrow$ 25 eV. The percent deviations of these fits from the tabulated values are generally small < 20% especially for Te > 0.5 eV.

Table 1 — Electron impact excitation rate coefficients of eight ground state vibrational levels of N_2 (cm^3/sec)

T	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
0.1	5.16E-13	3.30E-16	1.45E-16	3.31E-17	1.34E-17	2.48E-18	1.48E-18	4.49E-20 *
0.2	1.77E-11	3.15E-12	1.79E-12	8.31E-13	4.69E-13	2.09E-13	1.37E-13	1.87E-14
0.3	1.42E-10	5.97E-11	3.60E-11	2.04E-11	1.31E-11	7.59E-12	5.15E-12	1.01E-12
0.4	4.58E-10	2.42E-10	1.48E-10	9.16E-11	6.27E-11	4.11E-11	2.85E-11	6.70E-12
0.5	9.17E-10	5.32E-10	3.27E-10	2.12E-10	1.51E-10	1.05E-10	7.44E-11	1.95E-11
0.6	1.43E-09	8.68E-10	5.32E-10	3.55E-10	2.50E-10	1.90E-10	1.35E-10	3.79E-11
0.7	1.91E-09	1.20E-09	7.30E-10	4.96E-10	3.71E-10	2.78E-10	2.00E-10	5.90E-11
0.8	2.33E-09	1.49E-09	9.05E-10	6.23E-10	4.73E-10	3.61E-10	2.61E-10	8.01E-11
0.9	2.67E-09	1.73E-09	1.05E-09	7.29E-10	5.60E-10	4.34E-10	3.16E-10	9.98E-11
1.0	2.95E-09	1.92E-09	1.16E-09	8.13E-10	6.31E-10	4,94E-10	3.61E-10	1.17E-10
1.1	3.16E-09	2.07E-09	1.25E-09	8.78E-10	6.87E-10	5.42E-10	3.99E-10	1.31E-10
1.2	3.31E-09	2.18E-09	1.31E-09	9.26E-10	7.29E-10	5.79E-10	4.27E-10	1.43E-10
1.3	3.41E-09	2.26E-09	1.35E-09	9.60E-10	7.50E-10	6.07E-10	4.49E-10	1.52E-10
1.4	3.48E-09	2.31E-09	1.38E-09	9.82E-10	7.81E-10	6.27E-10	4.65E-10	1.59E-10
1.5	3.51E-09	2.34E-09	1.39E-09	9.94E-10	7.94E-10	6.40E-10	4.76E-10	1.54E-10
1.6	3.52E-09	2.35E-09	1.40E-09	9.99E-10	8.01E-10	6.47E-10	4.83E-10	1.58E-10
1.7	3.51E-09	2.35E-09	1.39E-09	9.98E-10	8.02E-10	6.50E-10	4.86E-10	1.71E-10
1.8	3.49E-09	2.33E-09	1.38E-09	9.92E-10	8.00E-00	6.50E-10	4.87E-10	1.72E-10
1.9	3.45E-09	2.31E-09	1.37E-09	9.82E-10	7.94E-10	6.57E-10	4.85E-10	1.72E-10
2.0	3.41E-09	2.29E-09	1.35E-09	9.70E-10	7.85E-10	6.42E-10	4.82E-10	1.72E-10
2.1	3.36E-09	2.25E-09	1.32E-09	9.55E-10	7.76E-10	6.35E-10	4.78E-10	1.72E-10
2.2	3.30E-09	2.22E-09	1.30E-09	9.40E-10	7.65E-10	6.26E-10	4.72E-10	1.70E-10
2.3	3.24E-09	2.18E-09	1.28E-09	9.23E-10	7.52E-10	6.17E-10	4.65E-10	1.68E-10
2.4	3.18E-09	2.14E-09	1.25E-09	9.05E-10	7.39E-10	6.07E-10	4.58E-10	1.66E-10
2.5	3.11E-09	2.09E-09	1.22E-09	8.83E-10	7.26E-10	5.97E-10	4.51E-10	1.64E-10
2.6	3.05E-09	2.05E-09	1.20E-09	8.69E-10	7.11E-10	5.86E-10	4.43E-10	1.62E 10
2.7	2.98E-09	2.01E-09	1.17E-09	8.50E-10	7.09E-10	5.74E-10	4.35E-10	1.59E-10
2.8	2.92E-09	1.96E-09	1.15E-09	8.32E-10	6.83E-10	5.63E-10	4.27E-10	1.57E-10
2.9	2.85E-09	1.92E-09	1.12E-09	8.14E-10	6.68E-10	5.52E-10	4.18E-10	1.37E-10
3.0	2.79E-09	1.88E-09	1.09E-09	7.95E-10	6.54E-10	5.40E-10	4.10E-10	1.51E-10
3.1	2.73E-09	1.84E-09	1.07E-09	7.78E-10	6.40E-10	5.29E-10	4.02E-10	1.48E-10
3.2	2.67E-09	1.80E-09	1.04E-09	7.60E-10	6.25E-10	5.18E-10	3.93E-10	1.45E-10
3.3	2.61E-09	1.76E-09	1.02E-09	7.43E-10	6.12E-10	5.07E-10	3.85E-10	1.43E-10
3.4	2.55E-09	1.72E-09	9.98E-10	7.25E-10	5.99E-10	4.96E 10	3.77E-10	1.40E-10

* 4.49E-20 reads 4.49×10^{-20}

Table 1(Continued) — Electron impact excitation rate coefficients of eight ground state vibrational levels of N_2 (cm^3/sec)

T	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
3.5	2.49E-09	1.68E-09	9.75E-10	7.10E-10	5.86E-10	4.85E-10	3.70E-10	1.38E-10
3.6	2.44E-09	1.64E-09	9.52E-10	6.94E-10	5.73E-10	4.75E-10	3.62E-10	1.36E-10
3.7	2.38E-09	1.61E-09	9.31E-10	6.78E-10	5.61E-10	4.65E-10	3.54E-10	1.32E-10
3.8	2.33E-09	1.57E-09	9.10E-10	6.63E-10	5.49E-10	4.55E-10	3.47E-10	1.30E-10
3.9	2.28E-09	1.54E-09	8.90E-10	6.49E-10	5.37E-10	4.46E-10	3.40E-10	1.27E-10
4.0	2.23E-09	1.50E-09	8.70E-10	6.35E-10	5.26E-10	4.35E-10	3.33E-10	1.25E-10
4.1	2.18E-09	1.47E-09	8.51E-10	6.21E-10	5.14E-10	4.27E-10	3.26E-10	1.22E-10
4.2	2.14E-09	1.44E-09	8.32E-10	6.07E-10	5.04E-10	4.18E-10	3.19E-10	1.20E-10
4.3	2.09E-09	1.41E-09	8.14E-10	5.94E-10	4.93E-10	4.10E-10	3.13E-10	1.18E-10
4.4	2.05E-09	1.38E-09	7.97E-10	5.82E-10	4.83E-10	4.02E-10	3.07E-10	1.15E-10
4.5	2.00E-09	1.35E-09	7.80E-10	5.70E-10	4.73E-10	3.93E-10	3.01E-10	1.13E-10
4.6	1.95E-09	1.32E-09	7.64E-10	5.58E-10	4.63E-10	3.86E-10	2.95E-10	1.11E-10
4.7	1.92E-09	1.30E-09	7.48E-10	5.45E-10	4.54E-10	3.78E-10	2.89E-10	1.09E-10
4.8	1.88E-09	1.27E-09	7.32E-10	5.35E-10	4.45E-10	3.70E-10	2.83E-10	1.07E-10
4.9	1.85E-09	1.24E-09	7.18E-10	5.24E-10	4.36E-10	3.63E-10	2.78E-10	1.05E-10
5.0	1.81E-09	1.22E-09	7.03E-10	5.14E-10	4.28E-10	3.56E-10	2.72E-10	1.00E-10

Table II — N_2 Triplet excitation rate coefficients (cm^3/sec)

T	$A^3\Sigma$	$B^3\pi$	$C^3\pi$	$B'^3\Sigma$	$W^3\Delta$
0.1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.2	3.28E-23	1.39E-25	6.56E-33	9.35E-28	1.01E-25
0.3	1.08E-18	4.42E-20	7.61E-25	9.44E-22	2.73E-20
0.4	2.09E-16	2.62E-17	8.55E-21	1.00E-18	1.51E-17
0.5	5.17E-15	1.25E-15	2.37E-18	6.76E-17	6.93E-16
0.6	4.58E-14	1.66E-14	1.02E-16	1.15E-15	9.12E-15
0.7	2.24E-13	1.07E-13	1.52E-15	8.86E-15	5.85E-14
0.8	7.52E-13	4.37E-13	1.15E-14	4.15E-14	2.40E-13
0.9	1.96E-12	1.31E-12	5.61E-14	1.39E-13	7.25E-13
1.0	4.24E-12	3.16E-12	1.98E-13	3.71E-13	1.78E-12
1.1	8.03E-12	6.56E-12	5.57E-13	8.31E-13	3.72E-12
1.2	1.37E-11	1.19E-11	1.32E-12	1.64E-12	6.95E-12
1.3	2.16E-11	1.99E-11	2.72E-12	2.91E-12	1.18E-11
1.4	3.20E-11	3.08E-11	5.05E-12	4.79E-12	1.88E-11
1.5	4.49E-11	4.51E-11	8.62E-12	7.38E-12	2.81E-11
1.6	6.05E-11	6.29E-11	1.37E-11	1.08E-11	4.01E-11
1.7	7.87E-11	8.44E-11	2.07E-11	1.51E-11	5.50E-11
1.8	9.93E-11	1.09E-10	2.97E-11	2.04E011	7.30E-11
1.9	1.22E-10	1.38E-10	4.10E-11	2.66E-11	9.41E-11
2.0	1.47E-10	1.70E-10	5.46E-11	3.39E-11	1.19E-10
2.1	1.74E-10	2.05E-10	7.08E-11	4.21E-11	1.46E-10
2.2	2.03E-10	2.44E-10	8.95E-11	5.14E-11	1.77E-10
2.3	2.33E-10	2.84E-10	1.11E-10	6.15E-11	2.10E-10
2.4	2.64E-10	3.27E-10	1.34E-10	7.26E-11	2.47E-10
2.5	2.96E-10	3.72E-10	1.61E-10	8.44E-11	2.86E-10

Table II (Continued) — N_2 Triplet excitation rate coefficients (cm^3/sec)

T	$A^3\Sigma$	$B^3\pi$	$C^3\pi$	$B^3\Sigma$	$W^3\Delta$
2.6	3.29E-10	4.19E-10	1.88E-10	9.71E-11	3.28E-10
2.7	3.63E-10	4.67E-10	2.19E-10	1.10E-10	3.72E-10
2.8	3.97E-10	5.17E-10	2.51E-10	1.24E-10	4.19E-10
2.9	4.32E-10	5.68E-10	2.85E-10	1.39E-10	4.67E-10
3.0	4.67E-10	6.20E-10	3.21E-10	1.54E-10	5.17E-10
3.1	5.01E-10	6.72E-10	3.58E-10	1.69E-10	5.68E-10
3.2	5.36E-10	7.24E-10	3.96E-10	1.85E-10	6.21E-10
3.3	5.70E-10	7.77E-10	4.35E-10	2.01E-10	6.75E-10
3.4	6.05E-10	8.30E-10	4.76E-10	2.17E-10	7.30E-10
3.5	6.38E-10	8.82E-10	5.17E-10	2.34E-10	7.85E-10
3.6	6.72E-10	9.35E-10	5.59E-10	2.50E-10	8.41E-10
3.7	7.22E-10	9.87E-10	6.01E-10	2.67E-10	8.97E-10
3.8	7.38E-10	1.04E-09	6.43E-10	2.84E-10	9.54E-10
3.9	7.70E-10	1.09E-09	6.86E-10	3.00E-10	1.01E-09
4.0	8.01E-10	1.14E-09	7.29E-10	3.17E-10	1.07E-09
4.1	8.32E-10	1.19E-09	7.72E-10	3.33E-10	1.12E-09
4.2	8.62E-10	1.24E-09	8.15E-10	3.50E-10	1.18E-09
4.3	8.92E-10	1.29E-09	8.57E-10	3.66E-10	1.24E-09
4.4	9.21E-10	1.33E-09	8.99E-10	3.82E-10	1.29E-09
4.5	9.49E-10	1.38E-09	9.41E-10	3.98E-10	1.35E-09
4.6	9.77E-10	1.43E-09	9.83E-10	4.14E-10	1.40E-09
4.7	1.00E-09	1.47E-09	1.02E-09	4.29E-10	1.45E-09
4.8	1.03E-09	1.52E-09	1.06E-09	4.45E-10	1.51E-09
4.9	1.06E-09	1.56E-09	1.10E-09	4.60E-10	1.56E-09
5.0	1.08E-09	1.60E-09	1.14E-09	4.75E-10	1.61E-09

Table II (Continued) — N_2 Triplet excitation rate coefficients (cm^3/sec)

T	$A^3\Sigma$	$B^3\pi$	$C^3\pi$	$E^3\Sigma$	$W^3\Delta$
6.0	1.30E-09	1.97E-09	1.50E-09	6.08E-10	2.07E-09
7.0	1.46E-09	2.25E-09	1.79E-09	7.15E-10	2.44E-09
8.0	1.57E-09	2.45E-09	2.00E-09	7.97E-10	2.71E-09
9.0	1.64E-09	2.60E-09	2.16E-09	8.58E-10	2.91E-09
10.0	1.70E-09	2.75E-09	2.27E-09	9.04E-10	3.05E-09
11.0	1.73E-09	2.76E-09	2.35E-09	9.37E-10	3.14E-09
12.0	1.74E-09	2.79E-09	2.40E-09	9.59E-10	3.19E-09
13.0	1.74E-09	2.80E-09	2.42E-09	9.74E-10	3.22E-09
14.0	1.73E-09	2.80E-09	2.43E-09	9.82E-10	3.22E-09
15.0	1.72E-09	2.78E-09	2.42E-09	9.86E-10	3.20E-09
16.0	1.70E-09	2.76E-09	2.41E-09	9.85E-10	3.18E-09
17.0	1.67E-09	2.72E-09	2.39E-09	9.82E-10	3.14E-09
18.0	1.65E-09	2.69E-09	2.36E-09	9.76E-10	3.10E-09
19.0	1.62E-09	2.64E-09	2.33E-09	9.68E-10	3.05E-09
20.0	1.59E-09	2.60E-09	2.30E-09	9.59E-10	3.00E-09
21.0	1.56E-09	2.55E-09	2.26E-09	9.48E-10	2.96E-09
22.0	1.53E-09	2.50E-09	2.22E-09	9.36E-10	2.89E-09
23.0	1.50E-09	2.45E-09	2.19E-09	9.23E-10	2.84E-09
24.0	1.46E-09	2.43E-09	2.15E-09	9.11E-10	2.78E-09
25.0	1.43E-09	2.36E-09	2.10E-09	8.98E-10	2.72E-09

Table III — N_2 Singlet excitation rate coefficients (cm^3/sec)

T	$w^1\Delta_u$	$a^1\pi_g$	$a'^1\Sigma_u$	$a''^1\Sigma_u$
0.1	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.2	3.36E-29	3.16E-28	2.61E-28	0.00E+00
0.3	1.28E-22	5.98E-22	3.87E-22	9.31E-28
0.4	2.68E-19	8.66E-19	4.99E-19	2.94E-23
0.5	2.72E-17	7.05E-17	3.80E-17	1.52E-20
0.6	6.05E-16	1.36E-15	7.00E-16	9.95E-19
0.7	3.63E-15	1.14E-14	5.71E-15	2.00E-17
0.8	3.03E-14	5.70E-14	2.79E-14	1.93E-16
0.9	1.13E-13	2.02E-13	9.71E-14	1.13E-15
1.0	3.24E-13	5.59E-13	2.65E-13	4.67E-15
1.1	7.71E-13	1.30E-12	6.06E-13	1.50E-14
1.2	1.59E-12	2.63E-12	1.21E-12	3.99E-14
1.3	2.93E-12	4.79E-12	2.19E-12	9.14E-14
1.4	4.94E-12	8.07E-12	3.63E-12	1.86E-13
1.5	7.77E-12	1.27E-11	5.65E-12	3.47E-13
1.6	1.15E-11	1.90E-11	8.31E-12	5.97E-13
1.7	1.63E-11	2.70E-11	1.17E-11	9.66E-13
1.8	2.22E-11	3.71E-11	1.59E-11	1.48E-12
1.9	2.92E-11	4.94E-11	2.08E-11	2.17E-12
2.0	3.73E-11	6.40E-11	2.66E-11	3.07E-12
2.1	4.65E-11	8.09E-11	3.31E-11	4.20E-12
2.2	5.68E-11	1.00E-10	4.05E-11	5.57E-12
2.3	6.80E-11	1.22E-10	4.85E-11	7.23E-12
2.4	8.02E-11	1.46E-10	5.73E-11	9.16E-12
2.5	9.32E-11	1.73E-10	6.68E-11	1.14E-11

Table III (Continued) — N_2 Singlet excitation rate coefficients (cm^3/sec)

T	$w^1\Delta_u$	$a^1\pi_g$	$a'^1\Sigma_u$	$a''^1\Sigma_u$
2.6	1.07E-10	2.01E-10	7.68E-11	1.39E-11
2.7	1.21E-10	2.32E-10	8.74E-11	1.68E-11
2.8	1.36E-10	2.65E-10	9.84E-11	1.99E-11
2.9	1.52E-10	3.00E-10	1.10E-10	2.34E-11
3.0	1.68E-10	3.37E-10	1.22E-10	2.72E-11
3.1	1.84E-10	3.75E-10	1.34E-10	3.12E-11
3.2	2.01E-10	4.15E-10	1.46E-10	3.56E-11
3.3	2.17E-10	4.57E-10	1.59E-10	4.02E-11
3.4	2.34E-10	5.00E-10	1.72E-10	4.51E-11
3.5	2.51E-10	5.44E-10	1.85E-10	5.02E-11
3.6	2.68E-10	5.89E-10	1.98E-10	5.55E-11
3.7	2.85E-10	6.35E-10	2.11E-10	6.11E-11
3.8	3.01E-10	6.83E-10	2.24E-10	6.69E-11
3.9	3.18E-10	7.30E-10	2.37E-10	7.28E-11
4.0	3.35E-10	7.79E-10	2.50E-10	7.89E-11
4.1	3.51E-10	8.29E-10	2.63E-10	8.52E-11
4.2	3.67E-10	8.78E-10	2.76E-10	9.16E-11
4.3	3.83E-10	9.28E-10	2.88E-10	9.81E-11
4.4	3.99E-10	9.80E-10	3.01E-10	1.05E-10
4.5	4.14E-10	1.03E-09	3.13E-10	1.11E-10
4.6	4.29E-10	1.08E-09	3.25E-10	1.18E-10
4.7	4.52E-10	1.13E-09	3.37E-10	1.25E-10
4.8	4.58E-10	1.18E-09	3.49E-10	1.32E-10
4.9	4.72E-10	1.23E-09	3.61E-10	1.39E-10
5.0	5.09E-10	1.28E-09	3.72E-10	1.46E-10

Table III (Continued) — N_2 Singlet excitation rate coefficients (cm^3/sec)

T	$w^1\Delta_u$	$a^1\pi_g$	$a'^1\Sigma_u$	$a''^1\Sigma_u$
6.0	6.05E-10	1.78E-09	4.74E-10	2.15E-10
7.0	6.93E-10	2.23E-09	5.55E-10	2.80E-10
8.0	7.56E-10	2.63E-09	6.16E-10	3.36E-10
9.0	7.97E-10	2.98E-09	6.63E-10	3.85E-10
10.0	8.23E-10	3.28E-09	6.98E-10	4.25E-10
11.0	8.38E-10	3.52E-09	7.25E-10	4.59E-10
12.0	8.45E-10	3.73E-09	7.44E-10	4.87E-10
13.0	8.45E-10	3.92E-09	7.58E-10	5.09E-10
14.0	8.40E-10	4.07E-09	7.68E-10	5.27E-10
15.0	8.32E-10	4.20E-09	7.76E-10	5.42E-10
16.0	8.21E-10	4.30E-09	7.80E-10	5.54E-10
17.0	8.09E-10	4.39E-09	7.83E-10	5.64E-10
18.0	7.96E-10	4.47E-09	7.85E-10	5.72E-10
19.0	7.81E-10	4.53E-09	7.85E-10	5.78E-10
20.0	7.67E-10	4.58E-09	7.84E-10	5.82E-10
21.0	7.51E-10	4.63E-09	7.82E-10	5.85E-10
22.0	7.37E-10	4.66E-09	7.80E-10	5.88E-10
23.0	7.22E-10	4.69E-09	7.77E-10	5.89E-10
24.0	7.07E-10	4.71E-09	7.74E-10	5.90E-10
25.0	6.92E-10	4.72E-09	7.71E-10	5.90E-10

Table IV — N_2 Ionization, dissociative ionization and dissociation rate coefficients (cm^3/sec)

T	Ion.	Diss. Ion.	Diss.
0.1	0.00E+00	0.00E+00	0.00E+00
0.2	0.00E+00	0.00E+00	8.51E-31
0.3	8.30E-32	0.00E+00	1.04E-23
0.4	4.24E-26	0.00E+00	3.65E-20
0.5	1.17E-22	1.15E-31	5.06E-18
0.6	2.35E-20	4.23E-28	1.40E-16
0.7	1.06E-18	1.53E-25	1.57E-15
0.8	1.87E-17	1.30E-23	9.96E-15
0.9	1.76E-16	4.18E-22	4.33E-14
1.0	1.07E-15	6.84E-21	1.44E-13
1.1	4.74E-16	6.83E-20	3.94E-13
1.2	1.65E-14	4.71E-19	9.26E-13
1.3	4.76E-14	2.44E-18	1.93E-12
1.4	1.19E-13	1.01E-17	3.67E-12
1.5	2.64E-13	3.50E-17	6.46E-12
1.6	5.32E-13	1.05E-16	1.07E-11
1.7	9.92E-13	2.77E-16	1.67E-11
1.8	1.73E-12	6.61E-16	2.50E-11
1.9	2.86E-12	1.45E-15	3.60E-11
2.0	4.50E-12	2.96E-15	5.01E-11
2.1	6.80E-12	5.66E-15	6.78E-11
2.2	9.92E-12	1.03E-14	8.95E-11
2.3	1.40E-11	1.77E-14	1.16E-10
2.4	1.93E-11	2.94E-14	1.47E-10
2.5	2.60E-11	4.69E-14	1.82E-10

Table IV (Continued) — N_2 Ionization, dissociative ionization and dissociation rate coefficients (cm^3/sec)

T	Ion.	Diss. Ion.	Diss.
2.6	3.42E-11	7.25E-14	2.24E-10
2.7	4.41E-11	1.09E-13	2.71E-10
2.8	5.60E-11	1.59E-13	3.23E-10
2.9	7.01E-11	2.27E-13	3.82E-10
3.0	8.64E-11	3.17E-13	4.47E-10
3.1	1.05E-10	4.35E-13	5.18E-10
3.2	1.27E-10	5.85E-13	5.95E-10
3.3	1.51E-10	7.75E-13	6.79E-10
3.4	1.79E-10	1.01E-12	7.69E-10
3.5	2.09E-10	1.30E-12	8.66E-10
3.6	2.43E-10	1.66E-12	9.68E-10
3.7	2.80E-10	2.08E-12	1.08E-09
3.8	3.20E-10	2.59E-12	1.19E-09
3.9	3.65E-10	3.19E-12	1.31E-09
4.0	4.12E-10	3.89E-12	1.44E-09
4.1	4.64E-10	4.71E-12	1.58E-09
4.2	5.19E-10	5.65E-12	1.71E-09
4.3	5.78E-10	6.74E-12	1.88E-09
4.4	6.42E-10	7.96E-12	2.01E-09
4.5	7.08E-10	9.35E-12	2.16E-09
4.6	7.80E-10	1.09E-11	2.33E-09
4.7	8.55E-10	1.27E-11	2.49E-09
4.8	9.34E-10	1.46E-11	2.66E-09
4.9	1.02E-09	1.68E-11	2.84E-09
5.0	1.10E-09	1.92E-11	3.02E-09

Table IV (Continued) — N_2 Ionization, dissociative ionization and dissociation rate coefficients (cm^3/sec)

T	Ion.	Diss. Ion.	Diss.
6.0	2.19E-09	5.83E-11	5.04E-09
7.0	3.64E-09	1.33E-10	7.35E-09
8.0	5.41E-09	2.51E-10	9.84E-09
9.0	7.43E-09	4.18E-10	1.24E-08
10.0	9.66E-09	6.33E-10	1.50E-08
11.0	1.20E-08	8.96E-10	1.7[illegible]-08
12.0	1.45E-08	1.20E-09	2.01E-08
13.0	1.71E-08	1.55E-09	2.25E-08
14.0	1.97E-08	1.93E-09	2.49E-08
15.0	2.24E-08	2.35E-09	2.72E-08
16.0	2.50E-08	2.79E-09	2.94E-08
17.0	2.77E-08	3.25E-09	3.15E-08
18.0	3.03E-08	3.73E-09	3.36E-08
19.0	3.30E-08	4.23E-09	3.55E-08
20.0	3.56E-08	4.74E-09	3.74E-08
21.0	3.82E-08	5.26E-09	3.91E-08
22.0	4.07E-08	5.79E-09	4.09E-08
23.0	4.32E-08	6.33E-09	4.25E-08
24.0	4.56E-08	6.86E-09	4.41E-08
25.0	4.80E-08	7.40E-09	4.55E-08
26.0	5.04E-08	7.94E-09	4.70E-08
27.0	5.27E-08	8.47E-09	4.83E-08
28.0	5.50E-08	9.01E-09	4.97E-08
29.0	5.72E-08	9.54E-09	5.09E-08
30.0	5.94E-08	1.01E-08	5.21E-08

Table V — O_2 Ionization, dissociative ionization and dissociative attachment rate coefficients (cm^3/sec)

T	Ion.	Diss. Ion.	Diss. Att.
0.1	0.00E+00	0.00E+00	6.42E-30
0.2	7.01E-36	0.00E+00	1.89E-20
0.3	4.68E-27	0.00E+00	3.61E-17
0.4	1.27E-22	3.20E-30	1.78E-15
0.5	5.99E-20	4.13E-26	1.93E-14
0.6	3.71E-18	2.30E-23	9.58E-14
0.7	7.20E-17	2.14E-21	3.00E-13
0.8	6.74E-16	6.45E-20	7.01E-13
0.9	3.89E-15	9.19E-19	1.35E-12
1.0	1.60E-14	7.74E-18	2.25E-12
1.1	5.11E-14	4.45E-17	3.40E-12
1.2	1.36E-13	1.92E-16	4.76E-12
1.3	3.13E-13	6.64E-16	6.28E-12
1.4	6.45E-13	1.93E-15	7.93E-12
1.5	1.21E-12	4.90E-15	9.65E-12
1.6	2.12E-12	1.11E-14	1.14E-11
1.7	3.49E-12	2.28E-14	1.31E-11
1.8	5.45E-12	4.36E-14	1.48E-11
1.9	8.15E-12	7.80E-14	1.65E-11
2.0	1.18E-11	1.30E-13	1.81E-11
2.1	1.64E-11	2.13E-13	1.96E-11
2.2	2.24E-11	3.31E-13	2.10E-11
2.3	2.97E-11	4.95E-13	2.23E-11
2.4	3.87E-11	7.17E-13	2.36E-11
2.5	4.93E-11	1.01E-12	2.47E-11

Table V (Continued) — O_2 Ionization, dissociative ionization and dissociative attachment rate coefficients (cm^3/sec)

T	Ion.	Diss. Ion.	Diss. Att.
2.6	6.20E-11	1.39E-12	2.57E-11
2.7	7.67E-11	1.88E-12	2.67E-11
2.8	9.36E-11	2.49E-12	2.76E-11
2.9	1.13E-10	3.23E-12	2.84E-11
3.0	1.35E-10	4.14E-12	2.91E-11
3.1	1.59E-10	5.22E-12	2.97E-11
3.2	1.86E-10	6.50E-12	3.03E-11
3.3	2.16E-10	8.00E-12	3.08E-11
3.4	2.50E-10	9.75E-12	3.12E-11
3.5	2.86E-10	1.18E-11	3.15E-11
3.6	3.25E-10	1.40E-11	3.19E-11
3.7	3.68E-10	1.67E-11	3.21E-11
3.8	4.13E-10	1.96E-11	3.24E-11
3.9	4.62E-10	2.29E-11	3.25E-11
4.0	5.15E-10	2.65E-11	3.27E-11
4.1	5.71E-10	3.06E-11	3.28E-11
4.2	6.30E-10	3.51E-11	3.29E-11
4.3	6.93E-10	4.00E-11	3.29E-11
4.4	7.60E-10	4.54E-11	3.30E-11
4.5	8.30E-10	5.12E-11	3.29E-11
4.6	9.03E-10	5.76E-11	3.29E-11
4.7	9.81E-10	6.44E-11	3.29E-11
4.8	1.06E-09	7.18E-11	3.28E-11
4.9	1.15E-09	7.98E-11	3.27E-11
5.0	1.23E-09	8.83E-11	3.26E-11

Table V (Continued) — O_2 Ionization, dissociative ionization and dissociative attachment rate coefficients (cm^3/sec)

T	Ion.	Diss. Ion.	Diss. Att.
6.0	2.30E-09	2.08E-10	3.10E-11
7.0	3.71E-09	3.97E-10	2.89E-11
8.0	5.39E-09	6.63E-10	2.66E-11
9.0	7.33E-09	1.00E-09	2.45E-11
10.0	9.45E-09	1.42E-09	2.26E-11
11.0	1.17E-08	1.90E-09	2.08E-11
12.0	1.42E-08	2.45E-09	1.92E-11
13.0	1.67E-08	3.05E-09	1.78E-11
14.0	1.92E-08	3.70E-09	1.65E-11
15.0	2.19E-08	4.40E-09	1.54E-11
16.0	2.45E-08	5.13E-09	1.44E-11
17.0	2.72E-08	5.90E-09	1.35E-11
18.0	2.99E-08	6.69E-09	1.26E-11
19.0	3.25E-08	7.50E-09	1.19E-11
20.0	3.52E-08	8.33E-09	1.12E-11
21.0	3.79E-08	9.18E-09	1.06E-11
22.0	4.05E-08	1.00E-08	1.00E-11
23.0	4.31E-08	1.09E-08	9.49E-12
24.0	4.56E-08	1.18E-08	9.01E-12
25.0	4.81E-08	1.26E-08	8.58E-12
26.0	5.06E-08	1.35E-08	8.17E-12
27.0	5.31E-08	1.44E-08	7.80E-12
28.0	5.55E-08	1.53E-08	7.45E-12
29.0	5.79E-08	1.61E-08	7.13E-12
30.0	6.02E-08	1.70E-08	6.83E-12

Table VI — O_2 Electronic excitation rate coefficients (cm^3/sec)

T	$a^1\Delta$	$b^1\Sigma$	$B^3\Sigma$	$A^3\Sigma+c^3\Sigma+c^1\Delta$
0.1	6.45E-16	2.56E-18	0.00E+00	2.00E-29
0.2	2.18E-13	1.36E-14	3.02E-24	6.41E-20
0.3	2.17E-12	2.70E-13	6.83E-17	1.06E-16
0.4	7.87E-12	1.29E-12	1.26E-17	4.58E-15
0.5	1.82E-11	3.42E-12	5.07E-16	4.56E-14
0.6	3.30E-11	6.77E-12	8.10E-15	2.17E-13
0.7	5.17E-11	1.12E-11	6.44E-14	6.76E-13
0.8	7.36E-11	1.67E-11	3.14E-13	1.61E-12
0.9	9.81E-11	2.28E-11	1.09E-12	3.20E-12
1.0	1.24E-10	2.96E-11	2.99E-12	5.60E-12
1.1	1.52E-10	3.67E-11	6.84E-12	8.94E-12
1.2	1.81E-10	4.41E-11	1.37E-11	1.33E-11
1.3	2.11E-10	5.16E-11	2.46E-11	1.87E-11
1.4	2.41E-10	5.91E-11	4.07E-11	2.52E-11
1.5	2.70E-10	6.65E-11	6.32E-11	3.28E-11
1.6	3.00E-10	7.39E-11	9.28E-11	4.15E-11
1.7	3.29E-10	8.10E-11	1.30E-10	5.12E-11
1.8	3.58E-10	8.79E-11	1.77E-10	6.19E-11
1.9	3.85E-10	9.46E-11	2.32E-10	7.35E-11
2.0	4.13E-10	1.01E-10	2.96E-10	8.60E-11
2.1	4.39E-10	1.07E-10	3.70E-10	9.94E-11
2.2	4.64E-10	1.13E-10	4.53E-10	1.14E-10
2.3	4.89E-10	1.19E-10	5.45E-10	1.29E-10
2.4	5.12E-10	1.24E-10	6.45E-10	1.44E-10
2.5	5.35E-10	1.30E-10	7.54E-10	1.60E-10

Table VI (Continued) — O_2 Electronic excitation rate coefficients (cm^3/sec)

T	$a^1\Delta$	$b^1\Sigma$	$B^3\Sigma$	$A^3\Sigma + C^3\Sigma + C^1\Delta$
2.6	5.57E-10	1.35E-10	8.71E-10	1.77E-10
2.7	5.78E-10	1.39E-10	9.96E-10	1.94E-10
2.8	5.98E-10	1.44E-10	1.13E-09	2.12E-10
2.9	6.17E-10	1.48E-10	1.27E-09	2.30E-10
3.0	6.35E-10	1.52E-10	1.41E-09	2.48E-10
3.1	6.52E-10	1.56E-10	1.56E-09	2.67E-10
3.2	6.69E-10	1.60E-10	1.72E-09	2.86E-10
3.3	6.85E-10	1.64E-10	1.88E-09	3.05E-10
3.4	7.00E-10	1.67E-10	2.05E-09	3.25E-10
3.5	7.15E-10	1.70E-10	2.21E-09	3.44E-10
3.6	7.28E-10	1.74E-10	2.39E-09	3.64E-10
3.7	7.42E-10	1.76E-10	2.56E-09	3.84E-10
3.8	7.54E-10	1.79E-10	2.74E-09	4.03E-10
3.9	7.66E-10	1.82E-10	2.93E-09	4.23E-10
4.0	7.77E-10	1.85E-10	3.11E-09	4.43E-10
4.1	7.88E-10	1.88E-10	3.29E-09	4.63E-10
4.2	7.98E-10	1.90E-10	3.48E-09	4.82E-10
4.3	8.08E-10	1.92E-10	3.67E-09	5.02E-10
4.4	8.18E-10	1.95E-10	3.86E-09	5.21E-10
4.5	8.26E-10	1.97E-10	4.05E-09	5.40E-10
4.6	8.35E-10	1.99E-10	4.24E-09	5.59E-10
4.7	8.43E-10	2.01E-10	4.43E-09	5.78E-10
4.8	8.51E-10	2.03E-10	4.62E-09	5.97E-10
4.9	8.58E-10	2.05E-10	4.81E-09	6.16E-10
5.0	8.65E-10	2.07E-10	5.00E-09	6.34E-10

Table VI (Continued) — O_2 Electronic excitation rate coefficients (cm^3/sec)

T	$a^1\Delta$	$b^1\Sigma$	$B^3\Sigma$	$A^3\Sigma + C^3\Sigma + C^1\Delta$
6.0	9.18E-10	2.23E-10	6.88E-09	8.05E-10
7.0	9.50E-10	2.35E-10	8.63E-09	9.52E-10
8.0	9.68E-10	2.44E-10	1.02E-08	1.07E-09
9.0	9.77E-10	2.52E-10	1.17E-08	1.17E-09
10.0	9.79E-10	2.57E-10	1.29E-08	1.25E-09
11.0	9.77E-10	2.61E-10	1.41E-08	1.32E-09
12.0	9.72E-10	2.64E-10	1.51E-08	1.37E-09
13.0	9.64E-10	2.66E-10	1.60E-08	1.41E-09
14.0	9.54E-10	2.67E-10	1.68E-08	1.44E-09
15.0	9.43E-10	2.67E-10	1.76E-08	1.46E-09
16.0	9.31E-10	2.66E-10	1.82E-08	1.48E-09
17.0	9.18E-10	2.65E-10	1.88E-08	1.49E-09
18.0	9.04E-10	2.64E-10	1.94E-08	1.50E-09
19.0	8.91E-10	2.62E-10	1.99E-08	1.50E-09
20.0	8.76E-10	2.60E-10	2.03E-08	1.50E-09
21.0	8.62E-10	2.57E-10	2.07E-08	1.50E-09
22.0	8.48E-10	2.54E-10	2.11E-08	1.50E-09
23.0	8.34E-10	2.51E-10	2.14E-08	1.49E-09
24.0	8.20E-10	2.48E-10	2.17E-08	1.48E-09
25.0	8.06E-10	2.45E-10	2.19E-08	1.48E-09
26.0	7.92E-10	2.42E-10	2.22E-08	1.47E-09
27.0	7.79E-10	2.38E-10	2.24E-08	1.46E-09
28.0	7.66E-10	2.35E-10	2.26E-08	1.45E-09
29.0	7.53E-10	2.32E-10	2.28E-08	1.44E-09
30.0	7.40E-10	2.28E-10	2.30E-08	1.43E-09

Table VII — O_2 Vibrational excitation rates

T	V1	V2	V3
0.1	2.71E-11	1.40E-12	1.64E-13
0.2	8.72E-11	9.74E-12	2.22E-12
0.3	1.19E-10	1.77E-11	5.21E-12
0.4	1.28E-10	2.21E-11	7.51E-12
0.5	1.27E-10	2.39E-11	8.90E-12
0.6	1.21E-10	2.41E-11	9.58E-12
0.7	1.13E-10	2.36E-11	9.80E-12
0.8	1.05E-10	2.25E-11	9.74E-12
0.9	9.70E-11	2.14E-11	9.51E-12
1.0	8.98E-11	2.02E-11	9.18E-12
1.1	8.32E-11	1.90E-11	8.81E-12
1.2	7.72E-11	1.79E-11	8.42E-12
1.3	7.19E-11	1.68E-11	8.03E-12
1.4	6.70E-11	1.60E-11	7.65E-12
1.5	6.26E-11	1.49E-11	7.28E-12
1.6	5.87E-11	1.41E-11	6.93E-12
1.7	5.51E-11	1.33E-11	6.60E-12
1.8	5.18E-11	1.26E-11	6.29E-12
1.9	4.90E-11	1.19E-11	6.00E-12
2.0	4.62E-11	1.13E-11	5.73E-12
2.1	4.37E-11	1.08E-11	5.47E-12
2.2	4.14E-11	1.02E-11	5.23E-12
2.3	3.94E-11	9.77E-12	5.00E-12
2.4	3.75E-11	9.32E-12	4.80E-12
2.5	3.57E-11	8.90E-12	4.60E-12

Table VII (Continued) — Vibrational excitation rates

T	V1	V2	V3
2.6	3.41E-11	8.52E-12	4.42E-12
2.7	3.26E-11	8.19E-12	4.24E-12
2.8	3.11E-11	8.10E-12	4.08E-12
2.9	2.99E-11	7.51E-12	3.93E-12
3.0	2.86E-11	7.23E-12	3.79E-12
3.1	2.75E-11	6.94E-12	3.65E-12
3.2	2.64E-11	6.68E-12	3.52E-12
3.3	2.54E-11	6.44E-12	3.40E-12
3.4	2.44E-11	6.21E-12	3.29E-12
3.5	2.36E-11	6.99E-12	3.18E-12
3.6	2.27E-11	5.79E-12	3.07E-12
3.7	2.20E-11	5.60E-12	2.98E-12
3.8	2.12E-11	5.41E-12	2.88E-12
3.9	2.05E-11	5.24E-12	2.79E-12
4.0	1.98E-11	5.08E-12	2.71E-12
4.1	1.92E-11	4.92E-12	2.63E-12
4.2	1.87E-11	4.78E-12	2.56E-12
4.3	1.80E-11	4.63E-12	2.48E-12
4.4	1.75E-11	4.50E-12	2.41E-12
4.5	1.70E-11	4.38E-12	2.35E-12
4.6	1.65E-11	4.25E-12	2.29E-12
4.7	1.60E-11	4.14E-12	2.22E-12
4.8	1.56E-11	4.02E-12	2.17E-12
4.9	1.52E-11	3.91E-12	2.11E-12
5.0	1.48E-11	3.81E-12	2.06E-12

Table VIII — Excitation and ionization rate coefficients for N (cm^3/sec)

T	N 4S-2D	N 4S-2P	N 2D-2P	Ion.
0.1	7.23E-20	5.19E-25	1.87E-14	-
0.2	1.63E-14	3.96E-17	1.05E-11	-
0.3	1.19E-12	1.80E-14	9.22E-11	-
0.4	1.10E-11	3.91E-13	2.76E-10	-
0.5	4.52E-11	2.51E-12	5.35E-10	7.24E-23
0.6	1.10E-10	8.71E-12	8.34E-10	3.14E-20
0.7	2.15E-10	2.13E-11	1.14E-09	1.61E-18
0.8	3.58E-10	4.17E-11	1.45E-09	2.88E-17
0.9	5.33E-10	7.05E-11	1.75E-09	2.66E-16
1.0	7.33E-10	1.07E-10	2.03E-09	1.57E-15
1.1	9.52E-10	1.52E-10	2.30E-09	6.69E-15
1.2	1.18E-09	2.02E-10	2.54E-09	2.24E-14
1.3	1.42E-09	2.58E-10	2.78E-09	6.26E-14
1.4	1.67E-09	3.18E-10	2.99E-09	1.51E-13
1.5	1.91E-09	3.81E-10	3.19E-09	3.25E-13
1.6	2.15E-09	4.46E-10	3.38E-09	6.36E-13
1.7	2.39E-09	5.13E-10	3.56E-09	1.15E-12
1.8	2.63E-09	5.80E-10	3.72E-09	1.96E-12
1.9	2.87E-09	6.48E-10	3.87E-09	3.16E-12
2.0	3.07E-09	7.15E-10	4.02E-09	4.8E-12
2.1	3.29E-09	7.81E-10	4.15E-09	7.2E-12
2.2	3.49E-09	8.47E-10	4.28E-09	1.03E-11
2.3	3.69E-09	9.11E-10	4.39E-09	1.43E-11
2.4	3.88E-09	9.74E-10	4.51E-09	1.93E-11
2.5	4.06E-09	1.04E-09	4.61E-09	2.55E-11
2.6	4.23E-09	1.09E-09	4.71E-09	3.30E-11

Table VIII (Continued) — Excitation and ionization rate coefficients for N (cm^3/sec)

T	N 4S-2D	N 4S-2P	N 2D-2P	Ion.
2.7	4.40E-09	1.15E-09	4.80E-09	4.20E-11
2.8	4.56E-09	1.21E-09	4.89E-09	5.26E-11
2.9	4.71E-09	1.26E-09	4.97E-09	6.48E-11
3.0	4.86E-09	1.32E-09	5.05E-09	7.89E-11
3.1	5.00E-09	1.37E-09	5.12E-09	9.49E-11
3.2	5.13E-09	1.42E-09	5.19E-09	1.13E-10
3.3	5.26E-09	1.47F-09	5.26E-09	1.33E-10
3.4	5.38E-09	1.51E-09	5.32E-09	1.55E-10
3.5	5.50E-09	1.56E-09	5.38E-09	1.80E-10
3.6	5.61E-09	1.60E-09	5.43E-09	2.07E-10
3.7	5.72E-09	1.64E-09	5.89E-09	2.36E-10
3.8	5.82E-09	1.68E-09	5.93E-09	2.68E-10
3.9	5.91E-09	1.72E-09	5.97E-09	3.02E-10
4.0	6.01E-09	1.75E-09	6.00E-09	3.39E-10
4.1	6.09E-09	1.79E-09	6.04E-09	3.78E-10
4.2	6.18E-09	1.82E-09	6.07E-09	4.20E-10
4.3	6.26E-09	1.85E-09	6.10E-09	4.64E-10
4.4	6.34E-09	1.88E-09	6.13E-09	5.11E-10
4.5	6.41E-09	1.91E-09	6.15E-09	5.60E-10
4.6	6.48E-09	1.94E-09	6.18E-09	6.12E-10
4.7	6.55E-09	1.97E-09	6.20E-09	6.67E-10
4.8	6.61E-09	2.00E-09	6.22E-09	7.24E-10
4.9	6.67E-09	2.02E-09	6.24E-09	7.83E-10
5.0	6.73E-09	2.05E-09	6.25E-09	8.45E-10
6.0	7.18E-09	2.24E-09	6.36E-09	1.60E-9
7.0	7.45E-09	2.37E-09	6.37E-09	2.50E-9
8.0	7.59E-09	2.45E-09	6.21E-09	3.65E-9
9.0	7.64E-09	2.52E-09	6.18E-09	4.90E-9
10.0	7.63E-09	2.51E-09	6.09E-09	6.30E-9
11.0	7.58E-09	2.51E-09	5.97E-09	7.80E-9

Table IX — Excitation and ionization rate coefficients for O (cm^3/sec)

T	O 3P-1D	O 3P-1S	O 1D-1S	Ion.
0.1	1.21E-18	1.09E-28	3.06E-19	-
0.2	3.41E-14	1.85E-19	1.71E-14	-
0.3	1.20E-12	2.36E-16	7.07E-13	-
0.4	7.74E-12	8.59E-15	4.62E-12	-
0.5	2.48E-11	7.48E-14	1.43E-11	1.55E-20
0.6	5.52E-11	3.17E-13	3.04E-11	1.46E-18
0.7	9.96E-11	8.94E-13	5.19E-11	3.81E-17
0.8	1.57E-10	1.95E-12	7.74E-11	4.43E-16
0.9	2.25E-10	3.57E-12	1.05E-10	3.01E-15
1.0	3.01E-10	5.81E-12	1.35E-10	1.40E-14
1.1	3.84E-10	8.67E-12	1.64E-10	4.95E-14
1.2	4.70E-10	1.21E-11	1.94E-10	1.42E-13
1.3	5.60E-10	1.61E-11	2.23E-10	3.50E-13
1.4	6.50E-10	2.05E-11	2.50E-10	7.58E-13
1.5	7.40E-10	2.53E-11	2.76E-10	1.49E-12
1.6	8.30E-10	3.04E-11	3.01E-10	2.69E-12
1.7	9.18E-10	3.58E-11	3.25E-10	4.54E-12
1.8	1.00E-09	4.14E-11	3.47E-10	7.26E-12
1.9	1.09E-09	4.70E-11	3.67E-10	1.11E-11
2.0	1.16E-09	5.28E-11	3.86E-10	1.62E-11
2.1	1.24E-09	5.85E-11	4.04E-10	2.29E-11
2.2	1.31E-09	6.43E-11	4.20E-10	3.14E-11
2.3	1.38E-09	7.12E-11	4.35E-10	4.20E-11
2.4	1.45E-09	7.56E-11	4.48E-10	5.49E-11
2.5	1.51E-09	8.11E-11	4.61E-10	7.03E-11

Table IX (Continued) — Excitation and ionization rate coefficients for O (cm^3/sec)

T	O 3P-1D	O 3P-1S	O 1D-1S	Ion.
2.6	1.57E-09	8.64E-11	4.72E-10	8.84E-11
2.7	1.63E-09	9.17E-11	4.83E-10	1.09E-10
2.8	1.68E-09	9.67E-11	4.92E-10	1.34E-10
2.9	1.73E-09	1.02E-10	5.00E-10	1.61E-10
3.0	1.77E-09	1.06E-10	5.08E-10	1.92E-10
3.1	1.82E-09	1.11E-10	5.15E-10	2.26E-10
3.2	1.86E-09	1.15E-10	5.21E-10	2.64E-10
3.3	1.89E-09	1.19E-10	5.26E-10	3.05E-10
3.4	1.93E-09	1.23E-10	5.31E-10	3.51E-10
3.5	1.96E-09	1.27E-10	5.35E-10	4.00E-10
3.6	1.99E-09	1.31E-10	5.39E-10	4.53E-10
3.7	2.01E-09	1.34E-10	5.42E-10	5.09E-10
3.8	2.04E-09	1.38E-10	5.45E-10	5.70E-10
3.9	2.07E-09	1.41E-10	5.47E-10	6.34E-10
4.0	2.09E-09	1.44E-10	5.49E-10	7.03E-10
4.1	2.11E-09	1.46E-10	5.50E-10	7.75E-10
4.2	2.12E-09	1.49E-10	5.51E-10	8.51E-10
4.3	2.14E-09	1.52E-10	5.52E-10	9.30E-10
4.4	2.15E-09	1.54E-10	5.52E-10	1.01E-9
4.5	2.17E-09	1.56E-10	5.52E-10	1.10E-9
4.6	2.18E-09	1.58E-10	5.52E-10	1.19E-9
4.7	2.19E-09	1.60E-10	5.47E-10	1.29E-9
4.8	2.20E-09	1.63E-10	5.51E-10	1.38E-9
4.9	2.20E-09	1.64E-10	5.50E-10	1.49E-9
5.0	2.21E-09	1.65E-10	5.49E-10	1.59E-9
6.0	2.23E-09	1.76E-10	5.31E-10	2.75E-9
7.0	2.19E-09	1.79E-10	5.05E-10	4.25E-9
8.0	2.11E-09	1.78E-10	4.77E-10	5.90E-9
9.0	2.03E-09	1.75E-10	4.48E-10	7.70E-9
10.0	1.93E-09	1.70E-10	4.21E-10	9.40E-9

Table X — Ionization rate coefficient of NO (cm^3/sec)

T	Ion.	T	Ion.
0.1	0.00E+00	2.6	3.19E-10
0.2	1.27E-29	2.7	3.77E-10
0.3	8.55E-23	2.8	4.41E-10
0.4	2.34E-19	2.9	5.11E-10
0.5	2.80E-17	3.0	5.87E-10
0.6	6.94E-16	3.1	6.69E-10
0.7	7.01E-15	3.2	7.57E-10
0.8	4.03E-14	3.3	8.52E-10
0.9	1.59E-13	3.4	9.52E-10
1.0	4.80E-13	3.5	1.06E-09
1.1	1.20E-12	3.6	1.17E-09
1.2	2.58E-12	3.7	1.29E-09
1.3	4.98E-12	3.8	1.41E-09
1.4	8.78E-12	3.9	1.54E-09
1.5	1.44E-11	4.0	1.68E-09
1.6	2.24E-11	4.1	1.82E-09
1.7	3.31E-11	4.2	1.97E-09
1.8	4.71E-11	4.3	2.12E-09
1.9	6.47E-11	4.4	2.28E-09
2.0	8.64E-11	4.5	2.44E-09
2.1	1.12E-10	4.6	2.61E-09
2.2	1.43E-10	4.7	2.78E-09
2.3	1.79E-10	4.8	2.96E-09
2.4	2.20E-10	4.9	3.15E-09
2.5	2.67E-10	5.0	3.33E-09

Table X (Continued) — Ionization rate coefficient of NO (cm^3/sec)

T	Ion.	T	Ion.
6.0	5.45E-09	31.0	8.09E-08
7.0	7.93E-09	32.0	8.34E-08
8.0	1.07E-08	33.0	8.59E-08
9.0	1.36E-08	34.0	8.83E-08
10.0	1.68E-08	35.0	9.07E-08
11.0	2.00E-08	36.0	9.30E-08
12.0	2.32E-08	37.0	9.53E-08
13.0	2.66E-08	38.0	9.75E-08
14.0	2.99E-08	39.0	9.96E-08
15.0	3.32E-08	40.0	1.02E-07
16.0	3.66E-08	41.0	1.04E-07
17.0	3.99E-08	42.0	1.06E-07
18.0	4.31E-08	43.0	1.08E-07
19.0	4.63E-08	44.0	1.10E-07
20.0	4.95E-08	45.0	1.12E-07
21.0	5.27E-08	46.0	1.14E-07
22.0	5.57E-08	47.0	1.15E-07
23.0	5.88E-08	48.0	1.17E-07
24.0	6.17E-08	49.0	1.19E-07
25.0	6.47E-08	50.0	1.21E-07
26.0	6.75E-08		
27.0	7.03E-08		
28.0	7.30E-08		
29.0	7.57E-08		
30.0	7.84E-08		

Table XI — Electron momentum transfer rate coefficients in N_2, O_2 (cm^3/sec)

T	N_2	O_2	O
0.1	1.50E-08	6.76E-09	3.55E-09
0.2	2.53E-08	1.29E-08	7.08E-09
0.3	3.43E-08	1.86E-08	9.83E-09
0.4	4.41E-08	2.32E-08	1.22E-08
0.5	5.50E-08	2.67E-08	1.43E-08
0.6	6.63E-08	2.92E-08	1.62E-08
0.7	7.70E-08	3.12E-08	1.80E-08
0.8	8.69E-08	3.27E-08	1.97E-08
0.9	9.56E-08	3.40E-08	2.14E-08
1.0	1.03E-07	3.51E-08	2.29E-08
1.1	1.10E-07	3.62E-08	2.43E-08
1.2	1.16E-07	3.73E-08	2.57E-08
1.3	1.21E-07	3.83E-08	2.71E-08
1.4	1.25E-07	3.94E-08	2.84E-08
1.5	1.29E-07	4.06E-08	2.96E-08
1.6	1.32E-07	4.17E-08	3.08E-08
1.7	1.35E-07	4.30E-08	3.20E-08
1.8	1.37E-07	4.43E-08	3.31E-08
1.9	1.40E-07	4.56E-08	3.43E-08
2.0	1.42E-07	4.69E-08	3.54E-08
2.1	1.44E-07	4.83E-08	3.64E-08
2.2	1.45E-07	4.97E-08	3.75E-08
2.3	1.47E-07	5.11E-08	3.85E-08
2.4	1.49E-07	5.25E-08	3.95E-08
2.5	1.50E-07	5.39E-08	4.05E-08

Table XI (Continued) — Electron momentum transfer rate coefficients in N_2, O_2 (cm^3/sec)

T	N_2	O_2	O
2.6	1.51E-07	5.53E-08	4.14E-08
2.7	1.53E-07	5.67E-08	4.22E-08
2.8	1.54E-07	5.81E-08	4.31E-08
2.9	1.55E-07	5.95E-08	4.40E-08
3.0	1.57E-07	6.09E-08	4.47E-08
3.1	1.58E-07	6.23E-08	4.55E-08
3.2	1.59E-07	6.36E-08	4.63E-08
3.3	1.60E-07	6.49E-08	4.71E-08
3.4	1.61E-07	6.62E-08	4.78E-08
3.5	1.62E-07	6.75E-08	4.85E-08
3.6	1.64E-07	6.88E-08	4.91E-08
3.7	1.65E-07	7.00E-08	4.98E-08
3.8	1.66E-07	7.16E-08	5.04E-08
3.9	1.67E-07	7.24E-08	5.11E-08
4.0	1.68E-07	7.35E-08	5.16E-08
4.1	1.70E-07	7.47E-08	5.22E-08
4.2	1.72E-07	7.58E-08	5.27E-08
4.3	1.72E-07	7.69E-08	5.32E-08
4.4	1.73E-07	7.79E-08	5.39E-08
4.5	1.74E-07	7.90E-08	5.44E-08
4.6	1.76E-07	7.99E-08	5.47E-08
4.7	1.77E-07	8.09E-08	5.52E-08
4.8	1.78E-07	8.19E-08	5.56E-08
4.9	1.79E-07	8.28E-08	5.61E-08
5.0	1.80E-07	8.37E-08	5.66E-08

Table XI (Continued) — Electron momentum transfer rate coefficients in N_2, O_2 (cm^3/sec)

T	N_2	O_2	O
6.0	1.92E-07	9.17E-08	6.01E-08
7.0	2.04E-07	9.78E-08	6.26E-08
8.0	2.15E-07	1.02E-07	6.45E-08
9.0	2.25E-07	1.06E-07	6.58E-08
10.0	2.34E-07	1.09E-07	6.68E-08
11.0	2.42E-07	1.11E-07	6.75E-08
12.0	2.50E-07	1.13E-07	6.80E-08
13.0	2.57E-07	1.14E-07	6.83E-08
14.0	2.63E-07	1.15E-07	6.85E-08
15.0	2.68E-07	1.17E-07	6.86E-08
16.0	2.73E-07	1.16E-07	6.86E-08
17.0	2.77E-07	1.16E-07	6.86E-08
18.0	2.81E-07	1.17E-07	6.85E-08
19.0	2.84E-07	1.17E-07	6.84E-08
20.0	2.87E-07	1.17E-07	6.82E-08
21.0	2.84E-07	1.17E-07	6.80E-08
22.0	2.92E-07	1.17E-07	6.78E-08
23.0	2.94E-07	1.16E-07	6.76E-08
24.0	2.96E-07	1.16E-07	6.74E-08
25.0	2.97E-07	1.16E-07	6.72E-08
26.0	2.98E-07	1.16E-07	6.69E-08
27.0	2.99E-07	1.15E-07	6.66E-08
28.0	3.00E-07	1.15E-07	6.64E-08
29.0	3.01E-07	1.15E-07	6.61E-08
30.0	3.02E-07	1.14E-07	6.58E-08

Table XII — Parameters for equation (2)

Reaction	T(ev)	E_{th}(ev)	b_o	b_1	b_2
$e + N_2 \rightarrow N_2 (A^3\Sigma) + e$	0-5	6.17	-6.11E-10	3.07E-9	-2.57E-10
	5-25	6.17	6.29E-9	4.99E-10	-1.58E-11
$e + N_2 \rightarrow N_2 (B^3\pi) + e$	0-5	7.35	-5.29E-10	6.01E-9	-5.59E-10
	5-25	7.35	1.27E-8	6.94E-10	-2.37E-11
$e + N_2 \rightarrow N_2 (c^3\pi) + e$	0-5	11.03	2.45E-9	1.04E-8	-1.25E-9
	5-25	11.03	2.50E-8	-3.59E-10	1.95E-13
$e + N_2 \rightarrow N_2 (w^3\Delta) + e$	0-5	7.36	-1.20E-9	4.46E-9	-2.16E-10
	5-25	7.36	1.02E-8	1.32E-9	-4.15E-11
$e + N_2 \rightarrow N_2 (a^1\pi_g)$	0-5	8.54	-7.92E-10	3.95E-9	-1.25E-10
	5-25	8.54	5.68E-9	2.28E-9	-4.83E-11
$e + N_2 \rightarrow N + N$	0-5	9.76	-1.37E-9	2.92E-9	1.37E-9
	5-25	9.76	-3.63E-8	1.72E-8	-9.04E-11
$e + N_2 \rightarrow N_2^+ + 2e$	0-5	15.58	-7.87E-10	6.12E-9	1.04E-9
	5-25	15.58	-3.16E-8	1.70E-8	9.34E-11
$e + O_2 \rightarrow O_2 (a^1\Delta) + e$	0-5	0.98	-2.35E-10	6.62E-10	- 2.88E-11
	5-25	0.98	1.03E-9	-3.01E-10	-7.16E-12
$e + O_2 \rightarrow O_2 (b^1\Sigma) + e$	0-5	1.63	-2.78E-11	1.99E-10	-1.31E-11
	5-25	1.63	2.44E-10	8.89E-11	-1.88E-12
$e + O_2 \rightarrow O_2 (A^3\Sigma \text{ etc})^* + e$	0-5	4.3	-1.30E-10	5.49E-10	2.95E-11
	7-25	4.3	-1.15E-11	7.57E-10	-1.66E-11

Table XII (Continued) — Parameters for equation (2)

Reaction	T(ev)	E_{th}(ev)	b_o	b_1	b_2
$e + O_2 \rightarrow O_2 (B^3\Sigma) + e$	0.5	6.10	-3.94E-9	5.79E-9	5.19E-10
	5-25	6.1	-5.27E-9	9.37E-9	-1.45E-10
$e + O_2 \rightarrow O_2^+ + 2e$	0-5	12.06	3.03E-10	1.46E-9	9.27E-10
	5-25	12.06	-2.95E-8	1.08E-8	2.45E-10
$e + O_2 \rightarrow O^- + O$	0-5	4.20	2.85E-11	1.16E-10	-1.75E-11
	5-25	4.20	2.41E-10	-1.63E-11	3.58E-13
$e + NO \rightarrow NO^+ + e$	0-5	9.30	-2.78E-10	4.56E-9	1.01E-9
	5-25	9.30	-3.09E-8	1.46E-8	2.2E-10

* ($A^3\Sigma$ etc) means ($A^3\Sigma + c^3\Delta + c^1\Sigma$)

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